APEX Model Validation for CEAP

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September 9, 2010 Version

Introduction

The Agricultural Policy/Environmental eXtender (APEX) model was developed for use in whole farm/small watershed management. The model was constructed to evaluate various land management strategies considering sustainability, erosion (wind, sheet, and channel), economics, water supply and quality, soil quality, plant competition, weather and pests. Management capabilities include irrigation, drainage, furrow diking, buffer strips, terraces, waterways, fertilization, manure management, lagoons, reservoirs, crop rotation and selection, pesticide application, grazing, and tillage.

Besides these farm management functions, APEX can be used in evaluating the effects of global climate/CO_2 changes; designing environmentally safe, economically feasible landfill sites; designing biomass production systems for energy; and other spinoff applications. The model operates on a daily time step (some processes are simulated with hourly or shorter time steps) and is capable of simulating hundreds of years if necessary. Farms may be subdivided into fields, soil types, landscape positions, or any other desirable configuration.

The individual field simulation component of APEX is taken from the Environmental Policy Integrated Climate (EPIC) model, which was developed in the early 1980's to assess the effect of erosion on productivity (Williams et al. 1984). Various components from CREAMS (Knisel, 1980) and SWRRB (Williams et al. 1985) were used in developing EPIC and the GLEAMS (Leonard et al. 1987) pesticide component was added later. Since the 1985 National RCA application (Putman et al. 1988), the model has been expanded and refined to allow simulation of many processes important in agricultural management (Sharpley and Williams 1990; Williams 1995).

The drainage area considered by EPIC is generally a field-size area, up to about 100 ha, where weather, soils, and management systems are assumed to be homogeneous. The major components in EPIC are weather simulation, hydrology, erosion-sedimentation, nutrient cycling, pesticide fate, crop growth, soil temperature, tillage, economics, and plant environment control. Although EPIC operates on a daily time step, the optional Green and Ampt (1911) infiltration equation simulates rainfall excess rates at shorter time intervals (0.1 h).

The model offers options for simulating several other processes—five PET equations, six erosion/sediment yield equations, two peak runoff rate equations, etc. EPIC can be used to compare management systems and their effects on nitrogen, phosphorus, carbon, pesticides, and sediment. The management components that can be changed are crop rotations; tillage operations; irrigation scheduling; drainage; furrow diking; liming; grazing; tree pruning, thinning, and harvest; manure handling; and nutrient and pesticide application rates and timing.

The APEX model was developed to extend the EPIC model capabilities to whole farms and small watersheds. In addition to the EPIC functions, APEX has components for routing water, sediment, nutrients, and pesticides across complex landscapes and channel systems to the watershed outlet. APEX also has groundwater and reservoir components. A watershed can be subdivided as much as necessary to assure that each subarea is relatively homogeneous in terms of soil, land use, management, and weather. The routing mechanisms provide for evaluation of interactions between subareas involving surface runoff, return flow, sediment deposition and degradation, nutrient transport, and groundwater flow. Water quality in terms of nitrogen (ammonium, nitrate, and organic), phosphorus (soluble and adsorbed/mineral and organic), and pesticide concentrations may be estimated for each subarea and at the watershed outlet. Commercial fertilizer or manure may be applied at any rate and depth on specified dates or automatically. The GLEAMS pesticide model is used to estimate pesticide fate considering runoff, leaching, sediment transport, and decay. Because of routing and subdividing, there is no limit on watershed size.

The major uses of APEX have been dairy manure management to maintain water quality in Erath and Hopkins Counties, TX, (Flowers et al. 1996) and a national study to assess the effectiveness of filter strips in controlling sediment and other pollutants (Arnold et al. 1998a). The technical and theoretical documentation and user's manual for APEX is available at http://www.brc.tamus.edu/simulation-models/epicapex.aspx.

APEX History

We began developing APEX in 1996, but it is based on state-of-the-art technology taken from several mature and well-tested models. The EPIC model is essentially embedded in APEX to form the core. EPIC was developed in the early 1980's and has been tested and applied in many countries throughout the world (Gassman et al. 2005). Major concepts and components from other well-known and widely used and accepted models have been added to APEX. These models include ALMANAC (Kiniry et al. 1992), CENTURY (Parton et al. 1994), CERES (Jones and Kiniry 1986) , CLIGEN (Nicks and Lane 1989), CREAMS (Knisel 1980), GLEAMS (Leonard, et al. 1987), HYMO (Williams 1975a), MUSLE (Williams 1975b), RUSLE (Renard et al. 1997), SWRRB (Williams et al. 1985), SWAT (Arnold et al. 1998a), TR-55 (USDA-SCS 1986), and WEQ (Woodruff and Siddoway 1965). The EPIC/APEX development history was reported by Gassman et al. (2005).

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Testing and Evaluating the APEX Field-scale Model

Testing and evaluating the APEX model consists of two phases: verification and validation. Verification procedures aid in evaluating the reliability and accuracy of the model and inputs to ensure that computational solutions are consistent with known solutions. Validation evaluates the accuracy of a computational simulation by comparison with independent experimental data. As stated by Oberkampf and Trucano (2002), "In verification, the relationship of the simulation to the real world is not an issue. In validation, the relationship between computation and the real world, i.e., experimental data, is the issue." First, the model must be solved correctly—i.e. verified—and then it can be validated (Nash and Sutcliffe 1970).

Verification

The fundamental strategy of verification is to demonstrate that the conceptual model is correctly implemented in the program code and internal parameter settings by testing for errors in the model solutions. It also serves as a mechanism to test revised code, equations, and internal coefficients by comparing model outputs to known solutions or outputs from previous model versions. Verification activities mainly take two forms: stability testing and screening model outcomes. Stability testing ensures that the computer model runs across a wide range of management systems and environmental conditions without a hard failure, i.e., a FORTRAN run-time error. Screening model outcomes involves evaluating model solutions to ensure that the model reliably portrays known physical processes, that solutions are consistent with previous model solutions, and that geospatial biases or errors are identified.

For testing, we maintain a database of approximately 88,000 runs. We also maintain derivative databases, one containing approximately 16,000 runs and another with about 1,500 runs. The full database covers 16 crops, more than 2,500 soils, 66 climate zones, and a variety of management systems spread across the cropland areas of the United States.

The stability test executes APEX for each run in the database to ensure that the program code does not fail when confronted by unusual (although realistic) conditions. After resolving hard failures, the model run database is used to screen for incorrect solutions. The first screen evaluates the outputs to ensure that the model solutions make sense physically, i.e., the physical process model conforms to its theoretical constructs. Outputs from the runs are grouped to minimize confounding variation within each group. Grouping categories include region, crop, soil texture class, soil hydrologic group, irrigation class, and nutrient management scheme. Within each group, input functions and response functions are calculated as the mean values from all model inputs or outcomes.

Table 1 shows several tests of APEX. In test one, the data are grouped into region-soil texture classes and within each group, the continuous variables STIR (soil-tillage intensity rating) and MUSLE (soil erosion by water) are expected to be positively correlated. Test two illustrates a different type of test in which there are no grouping variables. The entire domain is classified into one of three tillage types (no-till, mulch-till, and conventional tillage), and the MUSLE response function is evaluated with respect to the classifications. Tests one and two are examples of input-response and classification-response tests, respectively. Test six shows a response-response test in which the domain is grouped and the two response functions are correlated. Tests five and seven show slightly different evaluation schemes.

An improved method was developed for evaluating simulated conservation practices physical effects. The effort draws on the Conservation Practice Physical Effects (CPPE) Analyzer, which was developed by an interdisciplinary team of NRCS field specialists. The site conditions used during development of the data were generic but generally indicate correct effects. The original purpose was for training employees on the effects of each individual conservation practice on each of the 78 officially recognized natural resource concerns. Those same resource concerns are now included in legislation and program regulations. CPPE now constitutes section V of the Field Office Technical Guide and serves as the official NRCS repository of conservation effects data. For that reason, it can be assumed that numbers generated by APEX are generally defensible if they correlate with the qualitative data contained in CPPE. Work was done at the Blackland Research Center that results in an electronic link between CPPE and APEX. This component is used to screen and check the validity of model solutions for runs having conservation practices. Solutions not correlating with CPPE are flagged and checked to determine if site or other conditions account for the conflict.

Two other methods for screening model data are (1) comparison of solutions to other model solution sets and (2) evaluation of model solutions for geospatial reliability by comparison to spatially referenced data. For instance, model estimated crop yields are compared to U.S. Department of Agriculture-National Agricultural Statistics Service (USDA-NASS) county yields; model estimated erosion are compared to NRI USLE estimates and NRI wind erosion estimates; and model-estimated nutrient losses are compared to nutrient losses reported in the MANAGE database.

Table 1 Physical process checks, APEX

Test #	Type *	Grouping Variables	Include From Domain	Classification Variable	Input Function	Response Function 1	Response Function 2	Expectation
				Tillage-Erosion Tests				
1	I-R	Region- Texture	All	None	Tillage Intensity (STIR)	MUSLE		Positive Correlation
2	C-R	None	All	Tillage Type		MUSLE		No-till < Mulch-till < Conventional
3	C-R	None	Southern/ Northern Plains, Dryland	Tillage Type		Wind Erosion		No-till < Mulch-till < Conventional
				Irrigation-Crop Yield Tests				
4	C-R	Region-Crop-Texture	Arid Climates	Irrigated / Dryland		Crop Yield		Irrigated Yields > Dryland Yields
				Hydrology Tests				
5	C-R	Region-Crop-Irrigation	All	Soil Hydrologic Group		Runoff		Group D > C > B > A
6	R-R	Region-Tillage	Dryland	None		Runoff	Percolation	Inverse correlation
5	C-R-R	Region-Tillage	Dryland	Soil Hydrologic Group (SHG)		Runoff (Q)	Percolation (PRK)	Q increases and PRK decreases as SHG goes from A to D
				Nutrient Tests				
6	R-R	Region-Texture-Nutrient Manage –ment Scheme	All except organic soils	None		Runoff	Soluble N lost w/ runoff	Positive Correlation
						Percolation	Soluble N lost w/ percolation	Positive Correlation
						MUSLE	N lost w/ sediment	Positive Correlation
						Runoff	Soluble P lost w/ runoff	Positive Correlation
						Percolation	Soluble P lost w/ percolation	Positive Correlation
						MUSLE	P lost w/ sediment	Positive Correlation
7	I-R-R	Region-Crop-Texture	Dryland	None	Fertilizer Quantity Applied	Crop Yield	Total N loss	Yield and/or N loss tends to correlate w/ fertilizer quantity.

* Type column indicates the evaluation type. “I-R” indicates that the response function is analyzed with respect to the input function. “C-R” indicates that the response function is compared across classes (such as tillage system). “R-R” indicates two response functions analyzed together. Other codes are based on these three.

Validation

The fundamental strategy of validation is to assess how accurately the computational results compare with experimental or observed data, with quantified error and uncertainty estimates for both. The main issue is to provide evidence concerning how accurately the model simulates the real world. One component, calibration, assesses the sensitivity of model input parameters and adjusts the values of influential parameters so that simulation results closely match experimental results. Then the validation evaluates the accuracy of an APEX model simulation by comparison with independent experimental data.

Sensitivity Analysis

Wang et al. (2005a) demonstrated a procedure of combining sensitivity analysis, uncertainty analysis, and optimization procedures with the EPIC model. A further study integrated a model independent sensitivity analysis procedure, which was successfully tested for a drainage model DRAINMOD-N II (Wang et al. 2005b), into i-APEX (figure 1). Representative sets of APEX model data from across the United States (figure 2) were used to determine the influential parameters for APEX outputs (Wang et al. 2006c). Although sensitivities are dynamic in both temporal and spatial dimensions, the influential parameters appear very influential in most cases. The NRCS curve number index coefficient is very influential for runoff and water-related output variables, such as soil loss by water and N and P losses in runoff. The power parameter of the modified exponential distribution of wind speed (UXP) is very influential for wind erosion, and the fraction of humus in the passive pool (FHP) is very influential to soil organic carbon change. More details and the results can be seen in Wang et al. (2006c).

Figure 1 Integrating the sensitivity analysis component into i-APEX

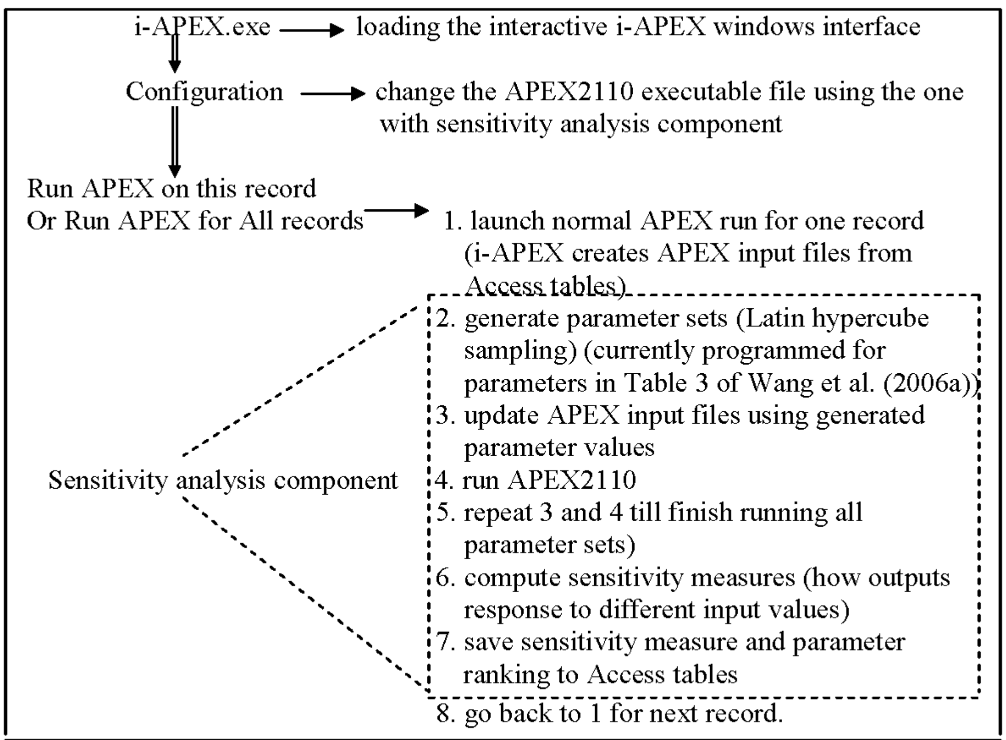
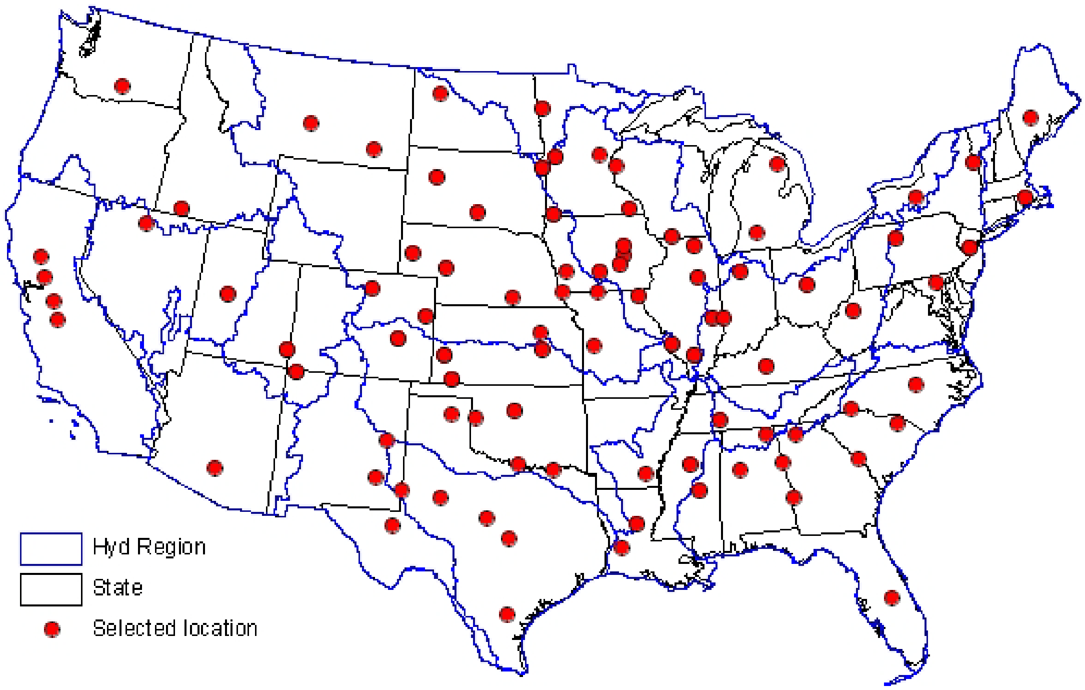


Figure 2 Locations of the selected APEX model dataset (from Wang et al. 2006c)



Recent APEX Validation Work

Table 2 summarizes the observed values and those simulated by EPIC/APEX for (1) a field-sized watershed (8.4 ha) near Riesel, Texas (31.1°N, 97.32°W); (2) a plot treatment experiment at the Arlington Agricultural Research Station in Wisconsin (43° 18′ N, 89° 21′ W); and (3) two small watersheds (34.4 and 43.3 ha) at the USDA Deep Loess Research Station near Treynor, Iowa (41°9´N, 95°38´W). In a previous study (Wang et al. 2006b) the EPIC model was evaluated using the data collected from six small cultivated watersheds (4.0 to 8.4 ha) by the U.S. Department of Agriculture-Agricultural Research Service (USDA-ARS) Grassland Soil and Water Research Laboratory near Riesel, Texas (Harmel et al. 2004). The study watersheds were fallow in 2001, cropped with corn (*Zea mays* L.) in 2002 and 2003, and planted to winter wheat (*Triticum aestivum* L.) in 2004. A target poultry litter application rate from 0 to 13.4 Mg ha^{-1} was randomly assigned to each of the watersheds. Watershed Y8 received the highest poultry litter rate each year. The crop yield, runoff, sediment, and nutrient losses from the watershed were simulated using APEX. Table 2 shows that the simulated results from both versions are reasonably close, and both agree well with the observed values.

The EPIC model was tested by Wang et al. (2005a) for corn yield and soil organic carbon for a long-term (1958-1991) experiment conducted at the University of Wisconsin-Arlington Agricultural Research Station in south-central Wisconsin. The responses of continuous corn to N fertilization were evaluated using a randomized complete block design with three levels of N. The block was divided into three plots (60 × 12 m) based on N fertilization rates at 0, 56, 112 kg N ha^{-1} from 1958 to 1962; at 0, 92, 184 kg N ha^{-1} from 1963 to 1972; and at 0, 140, 280 kg N ha^{-1} from 1973 to 1983 (Vanotti et al. 1997). In 1984, each of the non-control plots was split into two subplots to study the residual effects of previous N treatments. In 1985, each subplot was further subdivided into two to evaluate the effects of liming on corn yield. Soil organic carbon content in the top 0.2 m was measured in the initial year, 1958, and then in 1984 and 1990. The five treatments without liming were used in Wang et al. (2005a). The treatment with highest N fertilization rate was used to test APEX against the previous simulations using EPIC (table 2). The differences between the APEX and EPIC simulated annual average corn yield and soil organic carbon contents in 1984 and 1990 were within 2% of measured values.

The EPIC model was tested by Chung et al. (1999) using long-term data (1976–94) from two watersheds (W2 and W3). Approximately 94 percent of the watersheds were cropped in continuous corn (*Zea mays L.*) under two different tillage systems (conventional tillage at W2 vs. ridge-till at W3) for the study period, with perennial grass waterways located in the main valley drainage way. Average annual nitrogen application rate was 184 kg ha^{-1} for W2 (34.4 ha) and 165 kg ha^{-1} for W3 (43.3 ha). Wang et al. (2008) tested the CEAP APEX model using the same experiment data. Table 2 lists the annual average values for runoff, sediment, and crop yield, and 2 years of soil organic

Table 2 Testing APEX against previously published work using EPIC

	Measured		Simulated (EPIC)		Simulated (APEX)	
Riesel, TX (fallow in 2001, corn in 2002 and 2003, winter wheat in 2004). Data tested and listed below are for watershed Y8, with highest poultry litter rate (Wang et al., 2006b).						
2001-2004						
Runoff (mm)	238.7		259.1		225.7	
Sediment (Mg ha^{-1})	2.34		2.32		2.26	
Organic N (kg ha^{-1})	4.69		4.83		5.11	
Mineral N (kg ha^{-1})	15.45		15.50		15.87	
Organic P (kg ha^{-1})	1.79		2.33		2.25	
Soluble P (kg ha^{-1})	1.72		1.43		1.73	
2002-2003						
Corn yield (Mg ha^{-1})	6.04		5.82		6.23	
2004						
Wheat yield (Mg ha^{-1})	2.08		2.06		2.26	
Arlington, WI (34-yr continuous corn). Data tested and listed below are for treatment 9, with highest fertilization rate (Wang et al., 2005a).						
1958-1991						
Corn yield (Mg ha^{-1})	6.40		6.36		6.30	
1984						
Soil organic C (g m^{-2})	6526.8		6477.4		6362.43	
1990						
Soil organic C (g m^{-2})	6321.0		6475.2		6403.14	
1958-1990						
Average annual rate of C change (g m^{-2} yr^{-1})	24.1		28.7		26.54	
Treynor, IA (continuous corn). Data tested and listed below are for Watersheds 2 (W2) and 3 (W3) (Chung et al., 1999; Wang et al., 2008).						
1976-1994	W2	W3	W2	W3	W2	W3
Corn yield (Mg ha^{-1})	7.5	7.7	7.9	7.9	6.9	7.3
Runoff (mm)	66.5	33.1	67.6	37.1	67.6	33.0
Sediment yield (Mg ha^{-1})	12.94	1.71	-	-	12.52	1.67
1984						
Soil organic C (Mg ha^{-1}) ‡	22.3	35.1	-	-	23.9	32.0
1994						
Soil organic C (Mg ha^{-1}) ‡	26.6	34.7	-	-	29.1	36.4

‡ Soil organic carbon contents in the top 0.15 m of soil

carbon content in the top 0.15 m of soil. Enhanced methods of simulating tillage and the Universal Soil Loss Equation (USLE) crop management factor "C" factor are used in APEX, versus the EPIC model used by Chung et al. (1999). Accounting for grassed waterways present in the watersheds performed by Wang et al. (2008) allowed assessment of sediment losses at the watershed outlets, which Chung et al. (1999) could not evaluate. The long-term benefits of ridge-till versus conventional-tillage on runoff, sediment yield, crop yield, and soil organic carbon was also quantified by Wang et al. (2008) by conducting scenario analyses. Over the period 1976-1995, the predicted benefits of ridge-till versus conventional-tillage were a 36-39% reduction in surface runoff and a 82–86% reduction in sediment yield plus a 3.8% increase corn grain yield (Wang et al. 2008). The cumulative soil organic carbon losses with sediment were reduced about 63 to 67 percent.

Table 3 summarizes other APEX validations. The APEX model was tested using the daily runoff and sediment yield for both the pre- and post-Best Management Practice (BMP) conditions at the 22.5 km^2 Shoal Creek watershed within the Fort Hood military reservation in central Texas (31.4° N, 97.8° W) (Wang et al. 2009). About 26% of the watershed area was treated with contour ripping. A total of 211 gully plugs were installed within the watershed. The gully plugs were treated like small reservoirs with no permanent storage in APEX. APEX was calibrated for daily runoff and sediment yield. The R^2 values ranged from 0.60 to 0.80 and Nash-Sutcliffe efficiency (EF) ranged from 0.58 to 0.77, with one exception (the runoff EF was 0.33 for the pre-BMP validation.

The APEX model was field-tested using 6 years of data for flow, sediment, nutrient, and herbicides losses collected from nine small (2.58 to 2.74 ha) forested watersheds in southwest Cherokee County in east Texas (31°36´07"N, 95°14´12"W) (Wang et al. 2007). The predominant vegetation on the study watersheds was loblolly pine (Pinus taeda L.) under three silvicultural treatments, with three replicates for each of the following: (1) undisturbed control; (2) clear-cut followed by herbicide site preparation, replanting, and herbicide herbaceous release; and (3) clear-cut followed by herbicide site preparation, sub-soiling, fertilization, replanting, and herbicide herbaceous release. The EF values ranged from 0.68 to 0.94 for streamflow comparison, from 0.60 to 0.99 for sediment, 0.73 for imazapyr, and 0.65 for hexazinone based on annual level comparisons. Table 3 lists only the average values across the nine watersheds. More detail and the results for individual watersheds can be seen in Wang et al. (2007). A testing based on data from a runoff experiment plot (fallow) located in Lushan County, Central China's Henan Province, was also listed in table 3.

APEX was field-tested using 22 years data from two watersheds (denoted as W109 and W118) located in the North Appalachian Experimental Watershed (NAEW; 40°22′N, 81°48′W). The NAEW is a US Department of Agriculture research station in east-central Ohio near Coshocton. The watershed W109 has an area of 0.68 ha, an average slope length of 110 m, and an average slope of 13%. Watershed W118 has a size of 0.79 ha, an average slope of 132 m, and an average of 10%. The dominant soils within W109 is a Rayne silt loam (fine loamy, mixed, mesic Typic Hapludult; Haplic Alisol) and Berks silt loam (loamy-skeletal, mixed, mesic, Typic Dystrochrepts). The W118 has Coshocton silt loam (fine loamy, mixed, mesic Aquic Hapludalf; Haplic Luvisol) at the upper and middle slope positions and Clarksburg silt loam (fine loamy, mixed, mesic Aquic Hapludalf) at the lower slope position (Kelley et al., 1975). The cropping sequence was a conventional tillage corn (*Zea mays* L.)-winter wheat (*Triticum aestivum* L.)-meadow-meadow rotation from 1939 to 1970 in both watersheds. The management practices were plow-till corn from 1971 to 1975 (no till in 1974) and meadow from 1976 to 1983 in W118; conventional moldboard till corn from 1971 to 1978 and no till continuous corn from 1979 to 1983 in W109. The cropland management systems were practiced with corn-soybean (*Glycine max* L.) rotation since 1984, with chisel tillage in W109 and no till in W118.

Data including the timing of planting, tillage, harvest operations, fertilization, and climate data were collected to prepare APEX operation files for each watershed for the simulation period from 1984 to 2005. In general, corn or soybean were planted on the contour with a planter or no tillage drill in late April or early May. Ryegrass (*Lolium perenne* L.) was aerially seeded in September or October, and later killed with herbicides in April or May before the corn was planted. Corn and soybean were combine-harvested in October. N fertilizer was broadcast at the rate of 170-225 kg N ha^{-1} in Spring before planting corn.

The R^2 values for annual runoff and sediment yield were 0.87 and 0.73, respectively, during the calibration period (1984-1994). The EF for annual runoff and sediment yields were 0.89 and 0.73, respectively, during the validation period (1995-2005) (table 4). Corn and soybean grain yields were validated, with the R^2 values ranged from 0.71 to 0.87. The annual yield record was used to examine the ability of APEX to reproduce interannual yield variability (Figures 3 and 4). APEX captured the yields and yield trends reasonably well for both watersheds.

The percentage errors between the simulated and observed soil organic carbon in the top 30 cm in 1985 and 1999 were from -6.5% to 2.3% (table 5). Scenario analysis (1984-2005) indicated that the no-till practice at the two watersheds has insignificant impact on runoff and crop grain yield. However, the no till system reduced sediment yield by 57% to 79% and cumulative organic carbon losses in sediment yield were reduced by 37% to 63% compared with chisel tillage (table 6). The study shows that the APEX model is capable of predicting runoff, sediment yield, crop yields and soil organic carbon under different tillage systems.

More APEX calibration/validation studies are listed in table 7 and have been reviewed by Gassman et al. (2010). The study locations and performance statistics were summarized (table 7). The majority of studies reviewed report satisfactory EF and R^2 values based on the statistical criteria for establishing satisfactory water quality model performance proposed by Moriasi et al. (2007). Weak statistics were reported by Pushpa et al. (2009) for the validation period and by by Saleh et al. (2004) where the model was validated without calibration. They also cite issues with the monitoring data. In general, the model can replicate field research data reasonably well and it is a useful tool for evaluating complex landscape and management scenarios.

Table 3 APEX testing

	Observed	Simulated
Fort Hood, TX (range): Data listed below are average daily event-based values (Wang et al., 2009)		
Pre-BMP (1997-2001)	**Observed**	**Simulated**
Runoff (mm day^{-1})	14.1	13.9
Sediment (Mg ha^{-1} day^{-1})	0.99	0.98
Post-BMP (2002-2005)		
Runoff (mm day^{-1})	8.7	9.4
Sediment (Mg ha^{-1} day^{-1})	0.20	0.19
Alto, TX (forested watersheds). Data listed below are average annual values across nine watersheds, except that herbicide data are for six treated watersheds (Wang et al., 2007)		
1999-2004		
Runoff (mm)	57.0	56.9
Sediment (kg ha^{-1})	69.65	70.61
Organic N (kg ha^{-1})	0.41	0.49
Mineral N (kg ha^{-1})	0.17	0.18
Organic P (kg ha^{-1})	0.041	0.064
Soluble P (kg ha^{-1})	0.009	0.025
2002-2004		
Imazapyr (g ha^{-1})	1.332	1.248
Hexazinone (g ha^{-1})	0.190	0.149
Yuecun, Henan Province, China. Plot data (from help session for outside user at Nanjing Agricultural University, China).		
1982-1986		
(data are available for only 21 rainfall events)		
Runoff (mm)	20.9	16.2
Sediment (Mg ha^{-1})	1.82	2.06

Table 4. Measured versus simulated annual surface runoff (mm) and sediment yield (Mg ha^{-1}) from W118 at the North Appalachian Experimental Watershed for the calibration period 1984-1994 and validation period 1995-2005 (n=11 for each period).

		Measured		Simulated		PE (%)	EF	R^2
		Mean	Std	Mean	Std			
Runoff	Calibration	95.41	75.38	94.03	61.45	-1.5	0.86	0.87
	Validation	138.29	84.32	120.82	60.08	-12.6	0.79	0.89
Sediment	Calibration	0.74	0.83	0.80	1.01	8.4	0.60	0.73
	Validation	0.96	0.85	0.76	0.75	-20.4	0.67	0.73

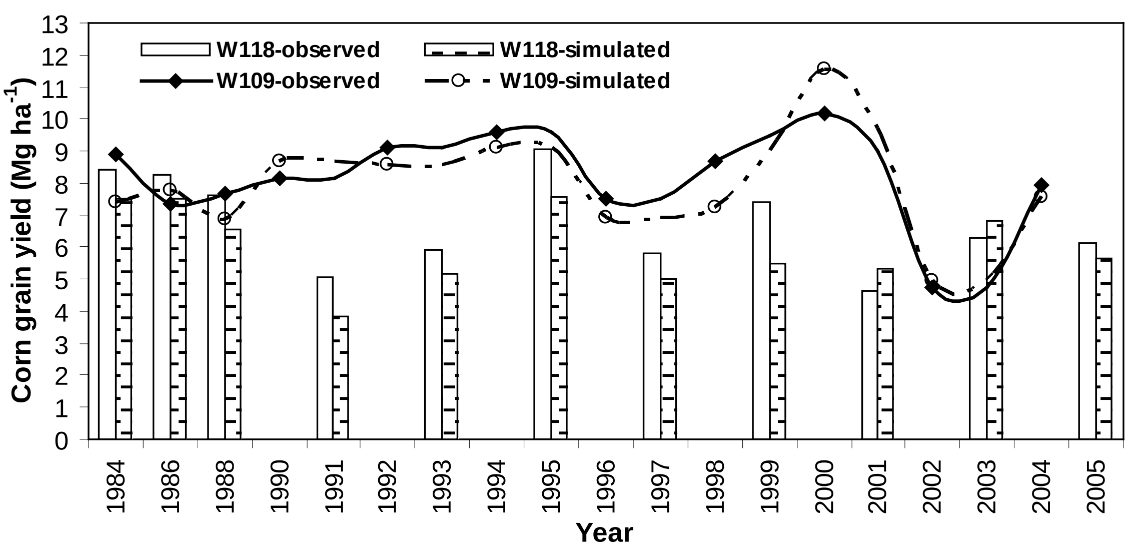


Figure 3. Observed and simulated dry corn grain yield at watersheds W109 and W118 at the North Appalachian Experimental Watersheds in Coshocton, OH.

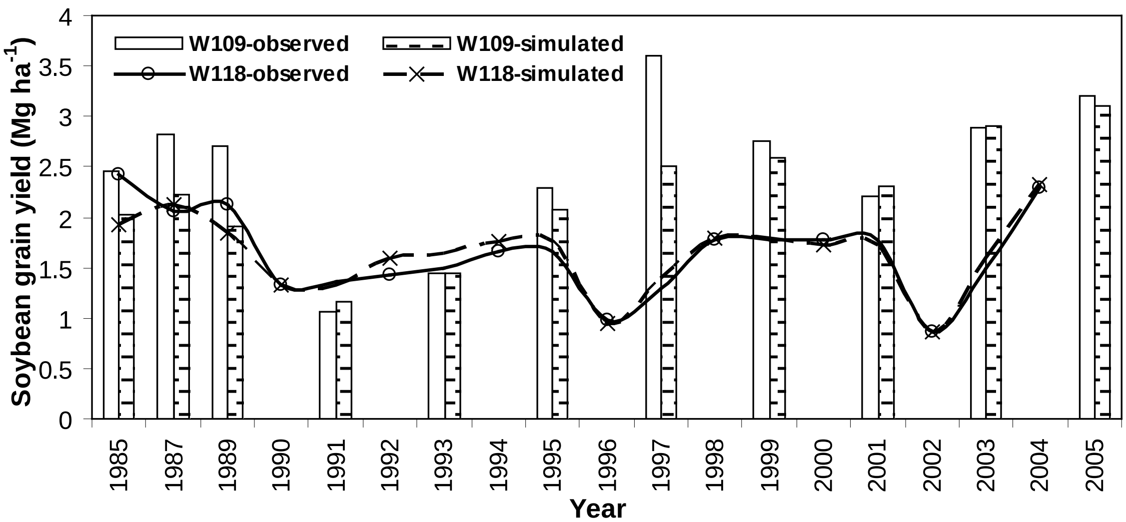


Figure 4. Observed and simulated dry soybean grain yield at watersheds W109 and W118 at the North Appalachian Experimental Watersheds in Coshocton, OH.

Table 5. Observed and simulated soil organic carbon in 0-30 cm depth at watersheds W109 and W118 at the North Appalachian Experimental Watersheds in Coshocton, OH.

Watershed	Year	Depth (cm)	Soil organic carbon (Mg C ha^{-1})		
			Observed	Simulated	% error
W109	1985[a]	0-30	33.7	34.3	1.8
	1999[b]	0-10	14.3	17.2	
		10-20	10.6	9.0	
		20-30	7.3	3.8	
		0-30	32.1	30.0	-6.5
W118	1985[a]	0-30	39.1	39.3	0.5
	1999[b]	0-10	18.1	21.2	
		10-20	12.3	11.4	
		20-30	6.5	5.1	
		0-30	36.8	37.6	2.3

[a] Observed values were from Hao et al. (2001)
[b] Observed values were from Hao et al. (2002)

Table 6. Simulated benefits of no till over chisel tillage at watersheds W109 and W118 at the North Appalachian Experimental Watersheds in Coshocton, OH **from 1984-2005.**

		W109			W118		
		Baseline (chisel tillage)	Scenario (no till)	Benefit[a] %	Baseline (no till)	Scenario (chisel tillage)	Benefit[a] %
Runoff	Observed (mm yr^{-1})	20.1	-		116.8	-	
	Predicted (mm yr^{-1})	23.7	22.1	-7.0	107.4	107.7	-0.2
	% error	18.3	-		-8.1	-	
Sediment yield	Observed (Mg ha^{-1} yr^{-1})	0.64	-		0.82	-	
	Predicted (Mg ha^{-1} yr^{-1})	0.78	0.34	-56.9	0.78	3.22	-78.7
	% error	22.8	-		-5.0		
Corn grain yield (dry)	Observed (Mg ha^{-1} yr^{-1})	8.16	-		6.77	-	
	Predicted (Mg ha^{-1} yr^{-1})	7.88	7.91	0.3	6.04	6.02	0.4
	% error	-3.4	-		-10.7	-	
Soybean grain yield (dry)	Observed (Mg ha-1 yr^{-1})	2.50	-		1.70	-	
	Predicted (Mg ha-1 yr^{-1})	2.21	2.22	0.8	1.66	1.65	0.5
	% error	-11.6	-		-2.6		
Cumulative Soil organic carbon loss in sediment	Predicted (Mg ha^{-1})	0.72	0.45	-37.3	1.08	2.96	-63.4

[a] Benefits were estimated as model output differences between chisel tillage and no tillage practices at both watersheds.

Table 7 Additional APEX calibration and validation reviewed in Gassman et al. (2009)

Reference	Watershed or test site	Indicator	Calibration	Validation
Gassman et al. (2006)	Research test plots (Nashua, Iowa & Lamberton, Minnesota)	Tile flow (monthly) Tile nitrate loss (monthly)	R^2 = 0.70 R^2 = 0.63	
Harman et al. (2004)	Aquilla Creek (central Texas)	Average annual corn yield	percentage error: -3.8 - 0.5%	
Mudgal et al. (2008)	Goodwin Creek, 14 research plots (north central Missouri)	Runoff (daily) Atrazine (daily)	R^2: 0.52 - 0.93 R^2: 0.52 - 0.91	R^2:0.62 - 0.98 R^2: 0.53 – 0.97
Pushpa et al. (2009)	Wasp Creek (central Texas)	Runoff (monthly) Sediment (monthly) Total nitrogen (monthly) Total phosphorus (monthly)	R^2= 0.71; NSE= 0.55 R^2= 0.68; NSE= 0.68 R^2= 0.75; NSE= 0.57 R^2= 0.65; NSE= 0.60	R^2= 0.66; NSE= 0.63 R^2= 0.17; NSE= 0.02 R^2= 0.38; NSE= 0.30 R^2= 0.27; NSE= 0.16
Saleh et al. (2004)	Nine forested watershed (eastern Texas)	Runoff (daily) Sediment (daily) Nutrient (daily)		NSE: 0.74 - 0.88 NSE: -1.4 - 0.78 NSE: -1.6 - 0.82
Wang et al. (2008)	Two Treynor watersheds (southwest Iowa)	Runoff (monthly) Sediment (monthly) Soil organic C in top 15 cm soil Average annual corn yield	NSE: 0.35 & 0.41 NSE: 0.32 & 0.36	NSE: 0.62 NSE: 0.41 & 0.72 percentage error: 5.0 & 9.2% percentage error: -5.0 & -3.0%
Wang et al. (2002)	Tierra Banco Creek (Texas)	Average annual sorghum yield	percentage error: -1.6%	
Wang et al. (2006a)	Zi-Fang-Gully (Shaanxi Province, China)	Runoff (annual) Sediment (annual) Average annual crop yield	percentage error: -10.3 - 15.0% percentage error: -13.3 - 7.6% percentage error: -5.3 - 5.6%	
Williams et al. (2006)	Bison feedlot (North Dakota)	surface runoff	R^2 : 0.72 - 0.73	
Yin et al. (2009)	Three plots, Middle Huaihe River watershed (Henan province, China)	Runoff (daily) Sediment (daily)	R^2: 0.56 - 0.98; NSE: 0.52 - 0.89 R^2: 0.66 - 0.88; NSE: 0.48 - 0.83	R^2: 0.72 - 0.77; NSE: 0.41 - 0.50 R^2: 0.55 - 0.85; NSE: 0.49 - 0.84

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